PWR Sump Performance Evaluation Methodology:

Velocity Calculation

Guidance:

To determine the transportability of debris, the velocity distribution of the liquid on the containment floor must be calculated. Two methods of performing this calculation are presented.

Simple Approach:

Using an electrical circuit analogy, the bulk velocity of liquid moving across the containment floor in discrete paths or channels may be calculated using a nodal network. The procedure for accomplishing this is as follows:

1.) The containment is segregated into discrete flow paths.
   - 1.1) Each flow path should have relatively constant hydraulic characteristics along the path length.
   - 1.2) A "node" is defined as the junction of two or more flow paths.
   - 1.3) Flow paths are connected or joined by nodes.
   - 1.4) The sump represents a terminal or "sink" node in the network.
   - 1.5) The break represents a supply or "source" node in the network.
   - 1.6) The source node may be moved to represent different break locations.
   - 1.7) Depending upon flow paths from the upper containment to the sump floor region, other supply or "source" nodes may be identified and located in the network.
   - 1.8) It is suggested that abrupt changes in hydraulic characteristics (specifically, abrupt changes in flow area) be treated by creating two flow paths connected by a node at the abrupt hydraulic change.

2.) Using reference manuals (such as I'delchek) and standard hydraulic practices, the hydraulic characteristics of each flow path are evaluated.
   - 2.1) Characteristic hydraulic length
   - 2.2) Characteristic hydraulic flow area
   - 2.3) Hydraulic loss coefficients for the entrance and exit of flow path in the network
   - 2.4) Select an appropriate correlation to represent the frictional losses associated with each characteristic hydraulic length. The correlation will be determined by surface roughness, etc.

3.) Several options exist for solving the hydraulic network to calculate bulk fluid velocities.
   - 3.1) First, a nodal network code may be applied to calculate bulk velocities
   - 3.2) Second, the network equations may be entered into an engineering calculation software package, such as TkSolver® and the software allowed to operate on the system of equations to obtain a solution.

3.3) A third solution is to enter the equations into a spreadsheet and solve them in an iterative manner.

4.) A sensitivity evaluation on fluid velocities and associated debris transport should be performed with the nodal network by varying the hydraulic parameters of the network. Based on the uncertainties typically associated with hydraulic loss coefficients and friction pressure drop correlations, a variation of $\pm$ 20 on the hydraulic parameters input to the fluid velocity calculation recommended.

Once the velocities in the network are solved for, an assessment of debris transport may be made as described below. This approach provides for the calculation of the bulk fluid velocity in each flow path about the containment floor.

Detailed Approach:

A detailed calculation of the flow patterns in the liquid pool on the containment floor may be calculated using a computational fluid dynamics (CFD) code. The model is constructed using detailed containment geometry information. This approach provides for detailed local fluid velocities throughout the model region.

Debris Transport Assessment:

The velocities calculated from one of the two methods listed above are compared to the transport data listed in the attached table.

1.) If the calculated fluid velocity is below the incipient transport velocity of the debris type being evaluated, that debris type will not transport and may be excluded from further consideration of sump blockage. Note that both the debris material and the debris geometry (size) determine the debris type.

2.) If the calculated fluid velocity is not sufficiently large enough to transport the debris type, compare the transport time to the settling velocity of the debris type and its distance from the sump to assess if it will settle prior to reaching the sump screen. Note that, typically, a linear velocity equal to about 7 times the settling velocity of the largest particle in the slurry of debris is required to maintain the particles in suspension (Reference 1).

3.) If the debris type settles, check if the local fluid velocity is sufficient to transport the debris type to the sump by tumbling or sliding along the containment floor.

4.) Consider if curbs and screens in the flow path to the sump.

4.1) Curbs provide an obstacle to debris types that would slide or tumble to the sump screen on the floor of the containment. For the debris type to continue to be transported to the sump, the local fluid velocity at the curb must be sufficiently large enough to lift the debris type over the curb.

4.2) Screens in the flow path can capture both suspended debris types and debris types tumbling or sliding along the containment floor.

4.3) The volume of debris type captured by either curbs or screens in the flow path is not considered for sump screen blockage.

4.4) However, the debris loading on intermediate screens in the flow path must be evaluated to determine if the resulting blockage may divert or hold up flow from the sump.

4.4.1) This is accomplished by first evaluating the amount of the various types of debris that might be collected by the intermediate screen.

4.4.2) The pressure drop across the intermediate screen is then calculated using the same method as applied to the sump screen.

5.) Debris types are to be considered in the debris loading on the sump screen if:

5.1) If the calculated fluid velocity is sufficiently large to transport the debris type to the sump without the debris type settling and the debris type can pass through intermediate screens in the flow path, or,

5.2) The calculated fluid velocity is sufficiently large to lift a debris type that is calculated to slide or tumble along the floor over a curb that is in the flow path.

References:

1. Durand and Condolinos, "Hydraulic Transport of Coal and Other Solid Materials in Pipes," (1952)

Debris Transport Reference Table

Material Category / Type	Incipient Transport Velocity (ft/sec)	Bulk Transport Velocity (ft/sec)	Lift-Over-Curb Velocity (ft/sec)	Terminal Settling Velocity (ft/sec)	Comment	Reference Document
A. Fibrous Insulation						
1. Fiberglass - Generic	Same as NUKON	Same as NUKON	Same as NUKON	Same as NUKON	Since no data for "generic fiberglass" is available, it is recommended that the data for NUKON be used to represent low-density fiberglass.	
2. Fiberglass – NUKON Microscopic Density = 175 lb/ft^3 Macroscopic Density = 2.4 lb/ft^3	0.06	0.09	0.22 (2-in. curb) 0.28 (6-in. curb)	0.41 (6-in.) 0.40 (4-in.) 0.15 (2-in.)	• Size not specified for transport velocity tests. The NUKON manufacturer created debris by using air jets. • NUREG/CR-6224 indicates that individual fibers and small groups of fibers settle at speeds less than 0.06 ft/sec	NUREG/CR-6772
3. Fiberglass – Temp-Mat Macroscopic Density = 11.3 lb/ft^3	See comment.	See comment.	See comment.	See comment.	No data specifically for Temp-Mat. Conservatively use data for NUKON (has a lighter macroscopic density).	
4. Fiberglass – Transco (Thermal Wrap®) a. Shredded b. 4-in. x 6-in. pieces c. Various Sizes – Transco Tests	a. 0.07 b. 0.12 c. Not Identified	a. 0.11 b. 0.16 c. 0.12-0.4 (15° C, size + type dependent)	a. 0.22 (2-in. curb) b. 0.25 (6-in. curb) c. Not identified	a. 0.13 b. Not Tested c. 0.09 – 0.51 (91° C, size dependent)	• Most limiting transport velocities were taken from NUREG/CR-6772. • Transco tested various sizes of debris for transport velocities. • Submersion of floating samples occurs within seconds for high temperatures (~90° C). • Settling velocity weakly dependent on temperature (higher velocities for higher temps)	a. NUREG/CR-6772 b. NUREG/CR-6772 c. Transco documents: ITR-92-03N, ITR-93-02N
5. Mineral Wool a. 4-in. x 4-in. x 1-in. b. Shreds	a. 0.4 b. 0.3	a. 1.4 b. See second comment	a. See second comment b. See second comment	a. See second comment b. See second comment	• Mineral Wool floats unless forced to sink. • No data specifically for Temp-Mat. Conservatively use data for NUKON.	NUREG/CR-2982
6. Miscellaneous Fibrous a. Asbestos b. Unibestos	a. See comment b. See comment	a. See comment b. See comment	a. See comment b. See comment	a. See comment b. See comment	No data specifically for asbestos or Unibestos. Conservatively use data for NUKON (has a light macroscopic density).	

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B. Calcium Silicate Insulation						
1. Generic – Chunks with dust + fibers	0.10 (dust + fibers) 0.25 (small chunks) 0.30 (larger chunks)	0.35	Not tested: see comment on dissolution	Not tested: see comment on dissolution	• Tests performed at ~20° C. • Chunks were almost fully dissolved after immersion in near-boiling water for 20 min.	NUREG/CR-6772
C. Reflective Metallic Insulation						
1. Stainless Steel a. Fragments – 0.5-in. x 0.5-in. b. Fragments – 2-in. x 2-in. c. Cassette – Half Assembly d. Covers – Inside and Outside e. Fragments – Various Sizes	a. 0.20 b. 0.28 c. 1.0 d. 0.7 e. Use values from (a) and (b) above	a. 0.22 b. 0.30 c. 1.0 d. 0.8 e. Use values from (a) and (b) above	a. 0.30 b. 0.30 (2-in. curb) >1.0 (6-in. curb) c. Use values from (b) above d. Use values from (b) above e. Use values from (b) above	a. 0.37 b. 0.48 c. Use values from (b) above d. Use values from (b) above e. 0.3-0.4 (size dependent)	• The lowest transport velocities from NUREG/CR-6772 were used. • Approx. 2/3 of RMI remained suspended in "chugging" tests (SEA document)	a. NUREG/CR-6772 b. NUREG/CR-6772 c. NUREG/CR-3616 d. NUREG/CR-3616 e. SEA 95-970-01-A:2
2. Aluminum a. Fragments – 2-in. x 2-in.	a. 0.20	a. 0.30	a. Use value from 1(b), stainless steel, above	a. 0.11	Use of Lift-over curb velocity for stainless steel is based on similar behavior for incipient transport velocity and bulk transport velocity.	NUREG/CR-6772
F. Fire Barrier						
1. 3M Interam	Same as NUKON	Same as NUKON -	Same as NUKON	Same as NUKON	With no data for 3M Interam available, recommend that data for low-density fiberglass be conservatively used.	
2. Fiberglass blanket	Same as NUKON	Same as NUKON	Same as NUKON	Same as NUKON	Since no data for "generic fiberglass" is available, it is recommended that the data for NUKON be used to represent low-density fiberglass.	
3. Kaowool a. Shredded b. 4-in. x 6-in.	a. 0.09 b. 0.12	a. 0.19 b. 0.16	a. 0.25 b. 0.25 (2-in. or 6-in. curb for both debris types)	a. 0.21 b. Use value from (a) above	Based on similarity of other hydraulic transport characteristics, suggest using same settling velocity for shredded and cut Kaowool.	NUREG/CR-6772
4. Marinite board a. 1-in. x 1-in. b. 4-in. x 4-in. Three values for density: Marinite-23 = 23 lb/ft^3 Marinite-36 = 36 lb/ft^3 Marinite-65 = 65 lb/ft^3	a. 0.77 b. 0.77	a. 0.79 b. >= 0.99	a. Not Tested b. Not Tested	a. 0.59 – 0.63 b. 0.42 – 0.60		NUREG/CR-6772

Material Category / Type	Incipient Transport Velocity (ft/sec)	Bulk Transport Velocity (ft/sec)	Lift-Over-Curb Velocity (ft/sec)	Terminal Settling Velocity (ft/sec)	Comment	Reference Document
5. Silicone foam	--	--	--	--	Floats – Readily transports at any velocity	NUREG/CR-6772
G. Other						
1. Koolphen (closed cell phenolic)	See comment.	See comment.	See comment.	See comment.	Suggest using data for NUKON.	
2. Min-K (microporous)	See comment.	See comment.	See comment.	See comment.	Suggest using data for NUKON.	
3. Lead Wool Macroscopic Density = 10-15 lb/ft^3	See comment.	See comment.	See comment.	See comment.	• Lead would settle and not transport. • Suggest using data for NUKON for fabric cover. • Confirm site use of lead wool blankets. (May not be used.)	
4. Dust / Dirt Density = 156 lb/ft^3	See comment.	See comment.	See comment.	See comment.	Although the density is large, sugges t using data for calcium silicate.	
5. Sludge (Iron) Density = 324 lb/ft^3	N/A	N/A	N/A	N/A	No credible source of iron sludge identified for PWR's.	
H. Coatings						
1. Epoxy – Generic Density = 90 lb/ft^3 (Nominal)	0.40	0.45	0.55 (2-in. curb)	0.15	• 0.55 ft/sec results in some transport over debris curb • Tests conducted in ambient temperature water	NUREG/CR-6772
2. Alkyd – Generic Density = 94 lb/ft^3 (Nominal)	See comment.	See comment.	See comment.	See comment.	Conservatively use data for epoxy coatings (has a lighter nominal density).	
3. Inorganic Zinc – Generic Density = 156 lb/ft (intact) = 437 lb/ft^3 (detached, Carboline) = 350 lb/ft^3 (detached, CRC)	See comment.	See comment.	See comment.	See comment.	Conservatively use data for epoxy coatings (has a lighter nominal density).	